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Bring colored pencils

10. PERIODICITY

INTRODUCTION

Most scientists recognize the Russian professor Dmitri Mendeleev as one of the giant figures in the history of chemistry. Yet Mendeleev did not propose any mind-shaking theory. Nor did he discover any new element—nor, for that matter, any new important compound. What Mendeleev discovered was more elusive, and much more important. He discovered a pattern of order in what appeared to be a jumble of unrelated facts about the chemical elements. Upon this order, Mendeleev built the periodic table. This turned out to be one of the most important models in the development of chemistry.

How did Mendeleev arrive at his discovery? In your text you have read that he considered first the physical properties of the elements. For example, he considered the melting points. Perhaps you have wondered how this could help. This activity should give you the answer.

What you will do is retrace, to some small extent, Mendeleev's steps. You will consider some important properties of the elements. Then you will plot these properties against the atomic numbers of the elements. Chemists often say that "the properties of the elements vary through cycles as the atomic numbers of the elements increase." Your graphs will help you see what these words mean. In this way you will get a firsthand feeling for what chemists call *periodicity*.

The properties you will consider in this activity are: the *melting points*, the *boiling points*, and the *atomic volumes* of the elements. The first two are not new to you. Notice, though, that in the table the values of these properties are not given on either the Celsius or the Fahrenheit scale. Instead, they are given on the absolute, or Kelvin, temperature scale.

The third property, atomic volume, is probably new to you. The atomic volume is defined as the volume occupied by a mass (in grams) of a *solid* element equal to the relative atomic mass of that element. For example, the atomic mass of iron is 55.85 amu (atomic mass units). A mass of iron equal to 55.85 g occupies a volume of 7.1 ml. Thus, the atomic volume of iron is 7.1 ml.

What about the elements that are gases or liquids at ordinary conditions? For example, what about gaseous hydrogen and liquid mercury? For these elements, the atomic volume must be determined when that element is in the solid state. Thus, the atomic volume of hydrogen is 14.0 *milliliters*. This, in fact, is the volume occupied by 1.00 g of *solid* hydrogen. (Hydrogen, you know, has an atomic mass of 1.00 amu.) However, 1.00 g of hydrogen (H_2) gas at ordinary conditions occupies a volume of about 12 *liters!*

MATERIALS NEEDED
graph paper variety of colored pencils

PROCEDURE

Part A. Making a graph of some properties of the elements

1. Use the data given in the table on the next page. Plot the melting point (in K) of each element against its atomic number. Plot the melting points on the vertical axis and the atomic numbers on the horizontal axis. Draw the graph connecting the plotted points.

If you need help in plotting the data, refer to the Appendix on graphing that begins on page 107.

2. Make a graph of the boiling points of the elements against their atomic numbers. Follow the same procedure you used in Step A-1 for the melting points.

3. Make a graph of the atomic volumes of the elements against their atomic numbers. Again, follow the same procedure as in Steps A-1 and A-2.

Part B. How do properties vary within a Group and across a period?

1. Refer to the periodic table of the elements on pages 98 and 99 of your *textbook*. Choose any three of the Groups of elements labeled I, II, ~~III, IV,~~ ~~VI,~~ VII, and VIII. Consider the graphs you plotted in Steps A-1, A-2, and A-3. On each graph, connect the points for the member elements of each Group you chose. Use a different-colored pencil for each Group.

2. Refer again to the periodic table. Choose any two of the five periods labeled 1, 2, 3, 4, and 5. Again consider each of the graphs you plotted in Steps A-...

A–2, and A–3. On each graph, connect the points for the member elements of each period you chose. Use a different-colored pencil for each period. If possible, try not to duplicate the colors you used to connect the points between member elements of the Groups you chose in Step B–1.

THINK ABOUT IT

1. The atomic volume of an element is something that need not be measured directly. You can calculate it if you know the density of the solid element. Choose one element that under ordinary conditions is a solid. Look up its density in a handbook. Then calculate its atomic volume. Check your answer against the value given for it in the table in this activity.

2. Which of the data you plotted in Part A demonstrates periodicity?

3. Consider the graphs you prepared in Part B. For each of the properties you plotted, what variation do you observe in (a) going down a Group, and (b) going across a period? Use your observations to draw a general statement about these properties of the elements.

4. How would the graphs you drew in Part A change if the temperatures had been given in Celsius degrees?

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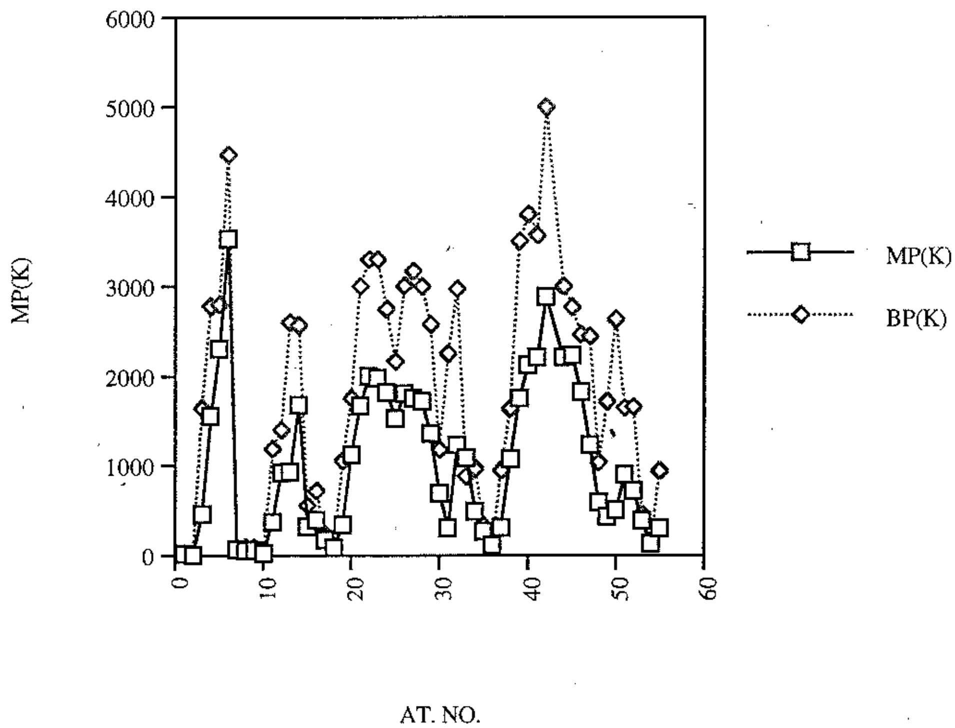
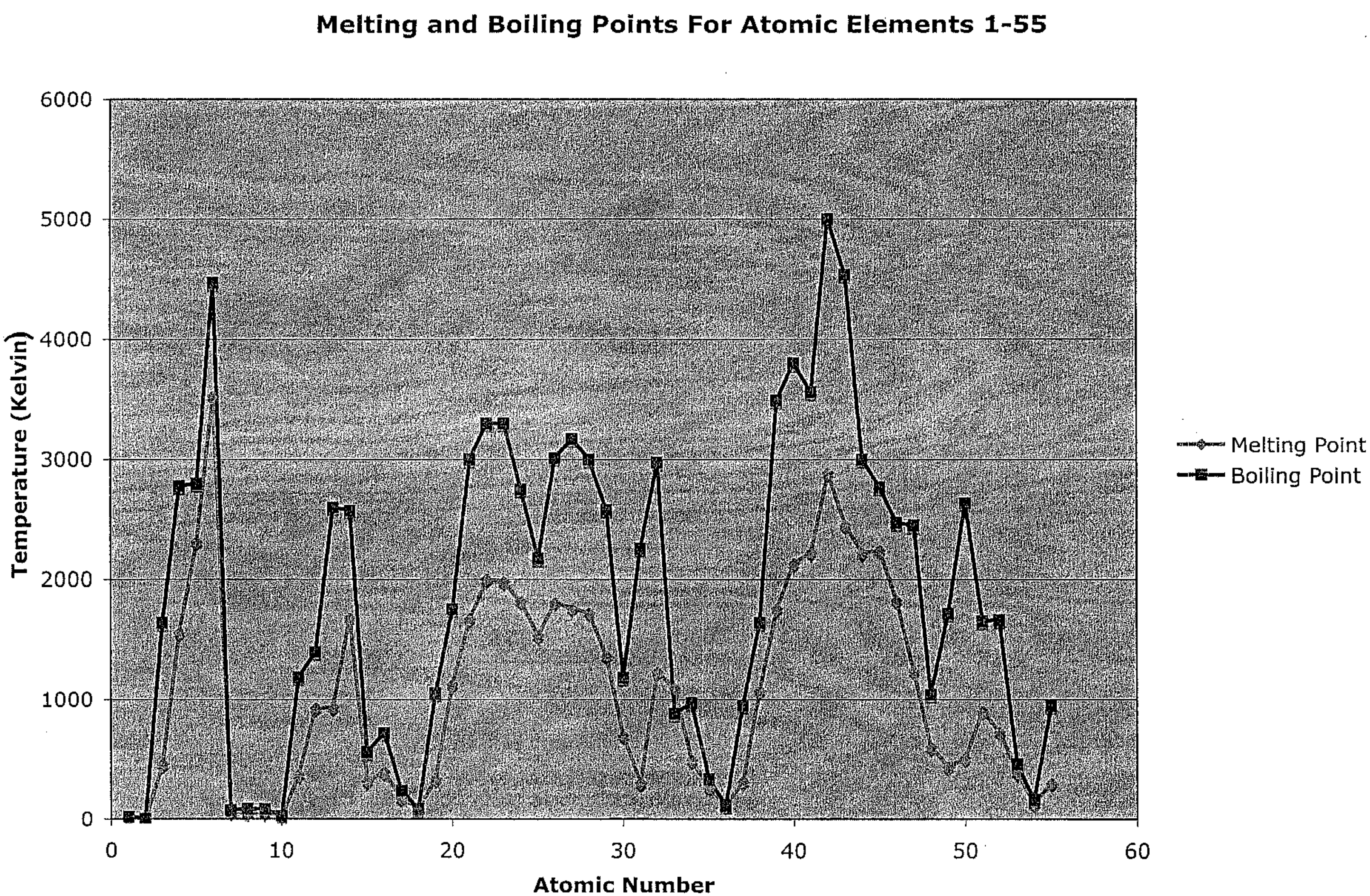
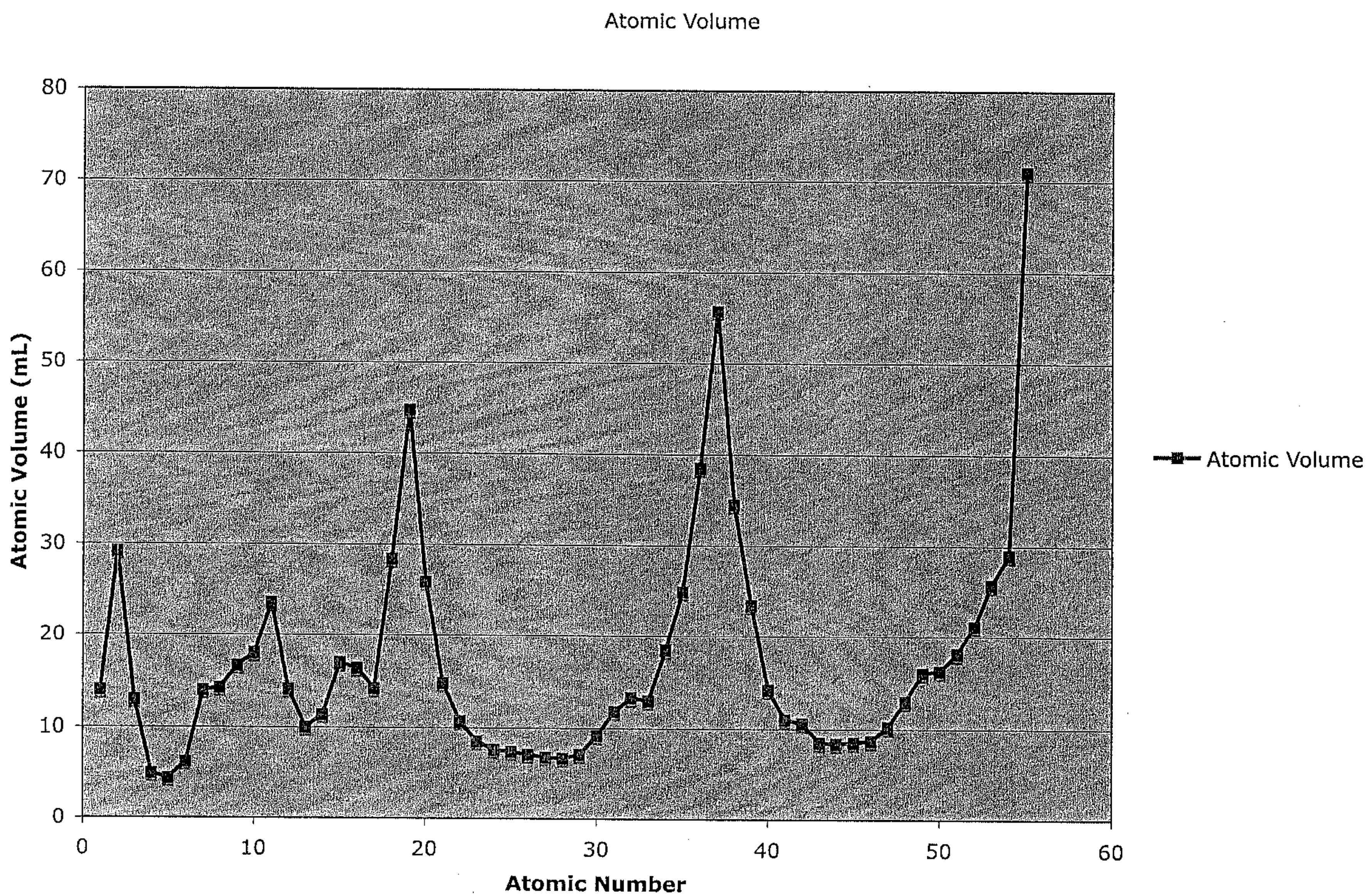
ATOMIC NUMBER	NAME	SYMBOL	MELTING POINT (K)	BOILING POINT (K)	ATOMIC VOLUME (ml)
1	Hydrogen	H	14	20	14.0
2	Helium	He	1	4	29.2
3	Lithium	Li	452	1640	13.0
4	Beryllium	Be	1557	2780	4.9
5	Boron	B	2310	2300	4.4
6	Carbon	C	3530	4470	6.2
7	Nitrogen	N	63	77	14.0
8	Oxygen	O	54	90	14.3
9	Fluorine	F	55	85	16.7
10	Neon	Ne	25	27	18.0
11	Sodium	Na	370	1187	23.6
12	Magnesium	Mg	923	1399	14.1
13	Aluminum	Al	932	2600	10.0
14	Silicon	Si	1680	2570	11.4
15	Phosphorus	P	317	553	17.0
16	Sulfur	S	392	718	16.4
17	Chlorine	Cl	172	239	14.2
18	Argon	Ar	84	87	28.4
19	Potassium	K	337	1052	44.7
20	Calcium	Ca	1124	1755	25.9
21	Scandium	Sc	1670	3000	14.8
22	Titanium	Ti	2000	3300	10.7
23	Vanadium	V	1980	3300	8.5
24	Chromium	Cr	1820	2750	7.6
25	Manganese	Mn	1530	2170	7.4
26	Iron	Fe	1808	3010	7.1
27	Cobalt	Co	1760	3170	6.8
28	Nickel	Ni	1725	3000	6.7
29	Copper	Cu	1360	2580	7.1
30	Zinc	Zn	694	1180	9.2
31	Gallium	Ga	303	2255	11.8
32	Germanium	Ge	1230	2973	13.3
33	Arsenic	As	1090	880	13.0
34	Selenium	Se	490	968	18.5
35	Bromine	Br	266	332	24.9
36	Krypton	Kr	116	120	38.5
37	Rubidium	Rb	312	950	55.8
38	Strontium	Sr	1073	1640	34.5
39	Yttrium	Y	1760	3500	23.5
40	Zirconium	Zr	2130	3800	14.2
41	Niobium	Nb	2220	3570	11.0
42	Molybdenum	Mo	2890	5000	10.6
43	Technetium	Tc	2430	4538	8.5
44	Ruthenium	Ru	2220	3000	8.4
45	Rhodium	Rh	2240	2770	8.5
46	Palladium	Pd	1830	2470	8.7
47	Silver	Ag	1234	2448	10.2
48	Cadmium	Cd	594	1040	13.0
49	Indium	In	430	1720	16.1
50	Tin	Sn	505	2635	16.3
51	Antimony	Sb	900	1653	18.2
52	Tellurium	Te	723	1660	21.2
53	Iodine	I	387	456	25.7
54	Xenon	Xe	133	164	29.0
55	Cesium	Cs	301	943	71.0

Melting point and Boiling point of the Periods




Melting and Boiling Points For Atomic Elements 1-55
Temperature (Kelvin)
6000
5000
4000
3000
2000
1000
0
0
10
20
30
40
50
60
Atomic Number
Melting Point
Boiling Point


Atomic Volume
Atomic Volume (mL)
0
10
20
30
40
50
60
70
80
Atomic Number
0
10
20
30
40
50
60
Atomic Volume

1°

THE PERIODIC LAW 17

The present organization of the elements is a product of the first periodic table published by Dmitri Mendeleev in 1869. The amazing accuracy of his predictions has been very important to chemists in this century. However, the basis of his arrangement was the atomic masses of the elements. This approach proved incorrect as it would have placed some elements in a family with dissimilar properties. Henry Moseley rearranged the table on the basis of the atomic numbers of the elements. In accordance with Moseley's revision, the **periodic law** states: *the properties of the elements are periodic functions of their atomic number.*

Each of the 106 known elements has its own set of characteristic properties. These range from solid to gas, lusterous to dull, low to high melting points, various colors, and so on. The elements are arranged within the periodic table into groups or families (vertical columns) and periods or rows (horizontal rows). This arrangement reflects the periodic or repeating nature of the properties of the elements.

In this experiment, you will use your knowledge of periodic properties and a list of clues to correctly arrange the elements from a scrambled periodic table. You will also predict values for any information missing from the table.

Objectives

In this exercise, you will

- arrange the elements in Groups IA-VIIIA according to a list of clues and your knowledge of periodic properties;
- predict the missing properties of each element based on location in the table; and,
- explain the trends of properties in families and periods.

EQUIPMENT

scissors
glue
blank periodic table

PROCEDURE

1. Locate Table 17-1 on page 237 of the Appendix. (Your teacher may provide a scrambled table for you.) Each block on the table represents a different element from Groups IA-VIIIA.
2. Cut out blocks A-Z. Use the following clues and arrange the elements in their proper order on Table 17-2 or blank table provided by your teacher. When you have placed these 26 elements in their correct position, glue them to Table 17-2, page 239.
   The following sets of elements belong together in groups: *ZRD, PSIF, JXBE, LHT, QKA, WOV, GUN, YMC.*
   J has an atomic number three times that of *T*.
   U has a total of six electrons.
   I_2A is the simple formula of an oxide.
   P is less dense than *S*.
   S is an alkali metal.
   E is a noble gas.
   W is a liquid.
   Z has the smallest atomic mass in its set.
   B has ten protons.
   O has an atomic number larger than *V*.
   D has the largest atomic mass of its set.
   C has five electrons in its outer energy level.
   F is a gas.
   X has an atomic number one higher than *F*.
   L is an alkaline earth element with atomic mass of 40.
   Y is a metalloid.
   O is a halogen.
   The atomic mass of *T* is more than that of *H*.
   Q has an atomic mass 2 times that of *A*.
   Atoms of *I* are larger than those of *S*.
   M has an atomic number one less than that of *A*.
   The electrons of atom *N* are distributed over three energy levels.
   The atomic radius of *K* is the largest of the set.
3. Cut out the remaining 16 blocks. Use the information provided in each block and your

knowledge of periodic properties to arrange these elements in their proper position on Table 17-2. Glue the blocks in place.

4. Some information is missing from each block. Predict the values for the missing items from the location of the element on the periodic table. Place your predictions on the table. (You may use the periodic table on the back inside cover only to determine the symbol for each element.)

CONCLUSIONS

1. Examine your completed table. What general observations can be made of trends within rows and groups for the following properties.
   a. density
   b. atomic radii
   c. melting point
2. Where are the heavy metals located? Give three examples.
3. List four physical properties which distinguish metals from nonmetals.
4. List the reason for the location of sodium in the periodic table.
5. Explain the relationship of oxidation numbers to electron configuration for Groups IA through VIIIA. How can an atom's electron configuration be predicted on the basis of its location in the periodic table?
6. Compare a corrected form of Table 17-2 with your table. (Your teacher will provide the corrected table.) Circle any elements that you placed in the wrong position. Describe the accuracy of your predictions for the missing values.

FURTHER INVESTIGATIONS

1. Observe samples of the elements in Period III and Group IA. Set up a table for these elements which contains data on the following physical properties: form and appearance, hardness, melting point, boiling point, density, and electrical conductivity. Use Table A-4 in the Appendix as a reference. On the basis of your observations explain why these properties are called periodic.
2. Prepare a graph of the atomic radii of the first 20 elements in the periodic table. Let the vertical axis represent the length of the radius in nanometers. Start with 0.050 nm and let each square represent an increase of 0.010 nm. Let the horizontal axis represent atomic number, with each block increasing in value from one to twenty. Use Table A-4 in the Appendix as a reference. Explain why the length of an atom's radius is considered to be a periodic property.

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Sequence
Chapter 10

Time
One lab period.
See Suggestion 1.

STUDENT ORIENTATION

Discuss the basis of the periodic table. Describe some periodic chemical and physical properties.

Review material on atomic number, atomic mass, electron configuration, and energy levels. Call attention to Table A-4 in the Appendix after the first portion of the laboratory.

Objectives

Upon completion of this exercise and when asked to demonstrate, diagram, or respond orally or on a written test, students will

- arrange elements into groups according to their similarities and differences; and
- predict properties within the families and periods.

EQUIPMENT

samples of elements from Period III and Group IA*

PROCEDURE

A. Safety Precautions

1. Samples of elements should be properly labelled with cautions imprinted on the labels. Caution students not to open the vials.*

B. Suggestions

1. This exercise can best be done as individuals and in the classroom. An alternative would be to assign this exercise as a homework assignment.

Table 17-1

EXAMPLE:

Atomic #		Symbol
Density	Code letter Oxidation #	Phase
Atomic radii		Melting point, °C

Row	IA	IIA	IIIA	IVA	VA	VIA	VIIA	VIIIA
1								
2								
3								
4								
5								
6								

25

0.0014 A gas 0.066 -218	0.0009 B gas 0.160 -249	1.82 C 0.115 44	5.90 D 0.122 29.8	0.0018 E gas 0.191 -189	0.00009 F gas 0.053 -259	5.32 G 0.123 937	1.85 H 0.111 1278
0.862 I 0.227 64	0.0037 J gas 0.198 -157	4.79 K 0.114 217	1.55 L 0.197 839	0.0013 M gas 0.070 -210	2.33 N 0.117 1410	0.003 O gas 0.099 -101	0.534 P 0.152 181
2.07 Q 0.104 113	2.70 R 0.143 660	0.971 S 0.192 98	1.74 T 0.160 649	2.27 U 0.077 3550	0.0016 V gas 0.072 -219	3.12 W liquid 0.111 -7	00018 X gas 0.122 -272
5.7 Y 0.125 817	2.34 Z 0.083 2079	1.53 1+ 0.248 39	7.31 2+, 4+ 0.141 232	6.69 3+ , 5+ 0.136 631	0.0059 gas 0 0.218 -112	1- 0.14 302	19.8 2+,4+ 0.167 254
9.75 3+,5+ 0.155 271	1.87 0.265 28	6.24 2-,4+,6+ 450	7.31 1+,3+ 0.163 157	4.93 1- 0.128	11.85 1+, 3+ 0.170 304	0.0097 gas 0 0.22 71	3.5 2+ 725
11.3 2+,4+ 0.175 328	2.54 2+ 0.215 769						

Table 12-6

Electronegativities

H 2.20																
Li 0.96	Be 1.50											B 2.02	C 2.56	N 2.81	O 3.37	F 4.00
Na 0.98	Mg 1.29											Al 1.63	Si 1.94	P 2.04	S 2.46	Cl 3.00
K 0.84	Ca 1.02	Sc 1.28	Ti 1.44	V 1.54	Cr 1.61	Mn 1.57	Fe 1.74	Co 1.79	Ni 1.83	Cu 1.67	Zn 1.60	Ga 1.86	Ge 1.93	As 2.12	Se 2.45	Br 2.82
Rb 0.85	Sr 0.97	Y 1.16	Zr 1.27	Nb 1.23	Mo 1.73	Tc 1.36	Ru 1.42	Rh 1.87	Pd 1.78	Ag 1.57	Cd 1.52	In 1.69	Sn 1.84	Sb 1.83	Te 2.03	I 2.48
Cs 0.82	Ba 0.93	*Lu 1.20	Hf 1.23	Ta 1.33	W 1.88	Re 1.46	Os 1.52	Ir 1.88	Pt 1.86	Au 1.98	Hg 1.72	Tl 1.74	Pb 1.87	Bi 1.76	Po 1.76	At 1.96
Fr 0.86	Ra 0.97	**														
	*La 1.09	Ce 1.09	Pr 1.10	Nd 1.10	Pm 1.07	Sm 1.12	Eu 1.01	Gd 1.15	Tb 1.10	Dy 1.16	Ho 1.16	Er 1.17	Tm 1.18	Yb 1.06		
	**Ac 1.00	Th 1.11	Pa 1.14	U 1.30	Np 1.29	Pu 1.25	Am 1.2 ←	Cm	Bk — estimated	Cf	Es	Fm	Md → 1.2			

Table 12-7

Character of Bonds

Electronegativity Difference	0.00	0.65	0.94	1.19	1.43	1.67	1.91	2.19	2.54	3.03
Percent Ionic Character	0%	10%	20%	30%	40%	50%	60%	70%	80%	90%
Percent Covalent Character	100%	90%	80%	70%	60%	50%	40%	30%	20%	10%

IONIZATION ENERGIES AND ELECTRONEGATIVITIES

Key: H — 313 = First Ionization Energy (kcal/mole of atoms); 2.2 = Electronegativity*

1	2	13	14	15	16	17	18
H 313 / 2.2							He 567
Li 125 / 1.0	Be 215 / 1.5	B 191 / 2.0	C 260 / 2.6	N 336 / 3.1	O 314 / 3.5	F 402 / 4.0	Ne 497
Na 119 / 0.9	Mg 176 / 1.2	Al 138 / 1.5	Si 188 / 1.9	P 242 / 2.2	S 239 / 2.6	Cl 300 / 3.2	Ar 363
K 100 / 0.8	Ca 141 / 1.0	Ga 138 / 1.6	Ge 182 / 1.9	As 226 / 2.0	Se 225 / 2.5	Br 273 / 2.9	Kr 323
Rb 96 / 0.8	Sr 131 / 1.0	In 133 / 1.7	Sn 169 / 1.8	Sb 199 / 2.1	Te 208 / 2.3	I 241 / 2.7	Xe 280
Cs 90 / 0.7	Ba 120 / 0.9	Tl 141 / 1.8	Pb 171 / 1.8	Bi 168 / 1.9	Po 194 / 2.0	At / 2.2	Rn 248
Fr / 0.7	Ra 122 / 0.9						

*Arbitrary scale based on fluorine = 4.0

Worksheet: Electronegativity, polar, nonpolar, and ionic bonds.

1. Arrange the following elements in order of increasing force of attraction between the nucleus and the electrons.

a. arsenic, gallium, germanium, radium, sulfur

b. aluminum, potassium, francium, nitrogen, iodine

2. Classify the bonds as polar, nonpolar, or ionic. Also include percentages.

a. boron-carbon

b. cesium-fluorine

c. fluorine-silicon

d. hydrogen-chlorine

e. magnesium-nitrogen

f. beryllium-fluorine

g. bromine-strontium

h. chlorine-lithium

i. chlorine-sodium

j. hydrogen-iodine

3. Fill in the chart.

Bond Pair	Electron Difference	% ionic	% covalent	ionic/covalent	polar/nonpolar/neither
a. sodium-oxygen					
b. hydrogen-bromine					
c. lead-sulfur					
d. carbon-nitrogen					
e. magnesium-iodine					

4. Know all definitions: ionic, covalent, polar, electronegativity, etc.

5. For each atom pair listed below, decide whether an ionic, polar, or nonpolar bond would form between the elements.

a. fluorine-astatine

b. boron-thorium

c. gadolinium-astatine

d. lanthanum-selenium

e. strontium-chlorine

f. iodine-sodium

5. The following pairs of atoms are all covalently bonded. Arrange the pairs in order of decreasing polarity of the bond pairs.

a. boron-nitrogen

b. carbon-sulfur

c. hydrogen-selenium

d. iodine-technetium

e. nitrogen-oxygen

f. aluminum-phosphorus

Properties of Metals and Nonmetals

	metals	nonmetals
a. ionization energy	low	high
b. electronegativity	low	high
c. luster	high	low
d. deformability	malleable and ductile	brittle
e. conductivity of heat and electricity	good	poor
f. phase at ordinary conditions	solid except for_____	gas or solid except for_____
g. ion formation	lose electrons to form positive ions	gain electrons to form negative ions
h. melting point	high	low
i. boiling point	high	low
j. metallic behavior	high due to few e-'s in highest energy level and are able to lose them easily	low due to many e-'s in highest energy and want to gain e-'s NOT lose e-'s

Trends	Groups	Periods
a. reactivity	increases for metals on left side of PT decreases for nonmetals on right side	increases for periods 1,2,3 decreases for periods 5,6,7
b. atomic number	increases	increases
c. atomic mass	increases	increases generally
d. density	increases	increases(metals) then decreases(nonmetals)

note: metals have greater density than nonmetals generally. Those with the greatest density are in periods 6 and 7, of the transitional metals and groups IIIA to VIA

e. melting point(metals)	decrease slightly then level off	increase slightly then decrease(due to the change from metals to nonmetals)
f. boiling point(metals)	"	"
g. melting point(nonmetals)	"	"
h. boiling point(nonmetals)	"	"

note: for periods, the MP/ BP is high and continues to increase as long as it is a metal/ metalloid but then decreases once it is a nonmetal and then continues to decrease. for period 2, the MP/ BP is higher than the other periods due to the e-'s being closer to the nucleus and it taking more energy to change the phase.

i. metallic behavior	increases due to e-'s being farther from the nucleus	decreases due to changing from metals to nonmetals
j. atomic radii(half the distance from two nuclei of a covalent bond)	increases due to more energy levels	decreases due to more attraction between e-'s and protons since there are more e-'s and protons
k. electronegativity (attraction for shared e-'s in a bond. How bad does it want an e-'s?)	decreases due to valence e-'s being further away from nucleus and a full octet still won't occur (except for group VIIA)	increased desire to gain e- since it will be closer to having a full octet

note: as electronegativity values decrease, metallic behavior increases due to NOT desiring an e-. it would rather get rid of an e-.

l. ionization energy(energy needed to remove an e- from a gaseous atom/ ion)	decreases due to e-'s being further from the nucleus and being easier to get rid of	increased energy needed to remove e- since e-'s are closer to nucleus and close to a full octet.
m. electron affinity(energy needed for a gaseous atom/ ion to acquire an e- and form a negative ion	constant with a slight increase metals-low(+)value or(-)value they don't want to gain e-'s they want to lose e-'s. group VIIIA(-) values and doesn't want to gain e-'s since it's a full octet already endothermic-energy absorbed	irratic -high values for non-metals(except VIIIA) and low/ negative values for metals and group VIIIA it wants to gain an e- if it will be more stable(full/ half full) exothermic-energy released

Worksheet: Periodic Trends: Atomic Radii, Ionization Energy, Electron Affinity

1. What is atomic radii?

2. Explain atomic radii's periodicity. How does it change within groups and periods? Why?

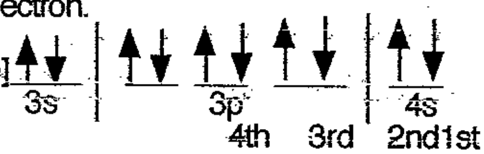
3. Arrange the following elements in order of increasing atomic radii:
cesium, aluminum, calcium, potassium, sulfur, and oxygen

4. What is ionization energy?

5. Explain ionization energy's periodicity. How does it change within groups and periods? Why?

5. State the long method orbital notation for the following. Then, state the 1st, 2nd, 3rd, and 4th electron that would be removed from that orbital notation. Keeping in mind the trends of ionization energy, state the amount of energy it would take to remove each electron—ionization difference between each successive electron (a little, medium, a lot). Include a justification for each electron.

Ex: Ca (20 e-'s) [Ne]



1st: a lot due to a full energy level.
2nd: a little due to its removal will make a full energy level
3rd: a lot due to a full energy level.
4th: medium due to its removal will not make a full, or half full energy level.

a. C

b. Ge

c. Zr

d. Na

6. What is electron affinity?

7. Explain positive(high and low) and negative values of electron affinity. State how electron affinity varies within a group and period. Why?

8. What is exothermic? endothermic?